Client-Side Web Acceleration for Low-Bandwidth Hosts

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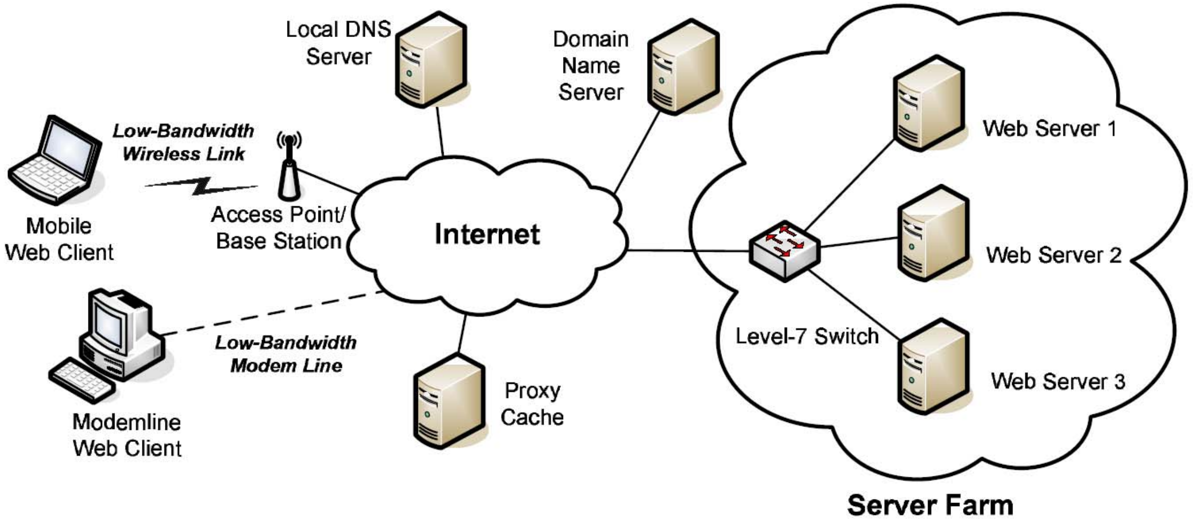
Introduction

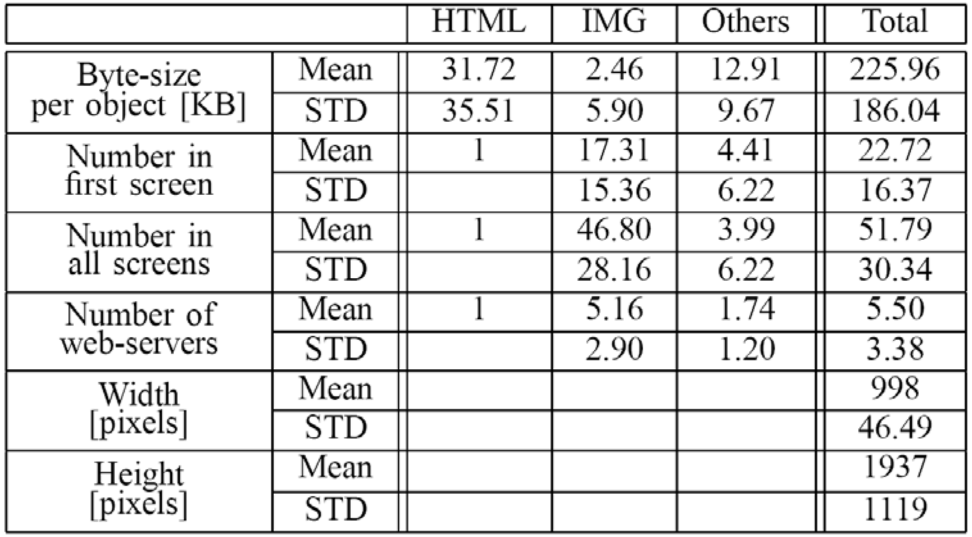
- Current Web optimization techniques
  - Web cache proxies, persistent connections (HTTP/1.1), content distribution networks (CDNs), WAP, BREW, etc.
  - Web browsers **still suffer** in low-bandwidth conditions.
    - Current fetching model of Web browsers is **not optimal** in low-bandwidth networks.
- Our contributions in this paper are:
  - Identification of the **problems that lead to inefficiency** of current Web browsers by carefully analyzing the interactions of several factors.
    - Screen contention problem
    - Bandwidth under-utilization problem
  - Proposal of **three mechanisms** to reduce Web response time in an *easy-to-deploy* fashion.
    - Prioritized fetching (PF)
    - Object reordering (OR)
    - Connection management (CM)

Current Web Access Model (1)



1) Load balancing can be performed by multiple Web servers.
   - A *layer-7 switch* dynamically **rewrites** domain names of objects in HTML.
   - Objects requests for a single Web page are delivered to multiple servers.
2) Multiple connections can be opened to a single Web server by browsers.
   - Internet Explorer and Netscape Navigator open up to 2 and 6 TCP connections to a single server, respectively.
   - A *parsing engine* in each browser inserts object requests to the message queues of the connections in a **round-robin** fashion.

Current Web Access Model (2)



		HTML	IMG	Others	Total
Byte-size per object [KB]	Mean	31.72	2.46	12.91	225.96
	STD	35.51	5.90	9.67	186.04
Number in first screen	Mean	1	17.31	4.41	22.72
	STD		15.36	6.22	16.37
Number in all screens	Mean	1	46.80	3.99	51.79
	STD		28.16	6.22	30.34
Number of web-servers	Mean	1	5.16	1.74	5.50
	STD		2.90	1.20	3.38
Width [pixels]	Mean				998
	STD				46.49
Height [pixels]	Mean				1937
	STD				1119

- Measurement of *comScore's Top 50 Web Sites*
  - Default full screen resolution: 1024 x 768 [pixels]
  - Pixel size of the client area in Internet Explorer: **1006 x 511** [pixels]
    - *Client area*: an effective area for displaying a Web page in a browser
    - *Screen*: a unit of an area, 1006 x 511 [pixels]
    - The size of a screen is equal to that of the client area.
  - Average number of screens per Web page: 1937pixels / 511pixels = **3.7**

Screen Contention Problem (1)

- What is Screen contention?
  1) Current Web browsers always perform **greedy** fetching.
     - They fetches the **entire** objects of a Web page, regardless of necessity.
  2) Users always perform partial Web-page accesses at any instant.
     - Only a **part** of a Web page can be accessed at a time, through the client area.
     - Users may not scroll down through the entire content of a Web page and leave.
  - Thus, fetching off-screen objects is not always necessary.
     - Fetching of necessary on-screen objects may be slowed down.
     - Objects from different screens compete for bandwidth: screen contention
- Why does screen contention occur?
  - Web browsers adopt an imperfect fairness model.
     - Browsers considers only fairness in the **number of objects per connections.**
     - Object requests are inserted to multiple connections in a **round-robin** fashion.
  - Disparity of cumulative transfer size among multiple connections
     - Connections having only small-sized objects may finish on-screen transmission early and begin to fetch off-screen objects.

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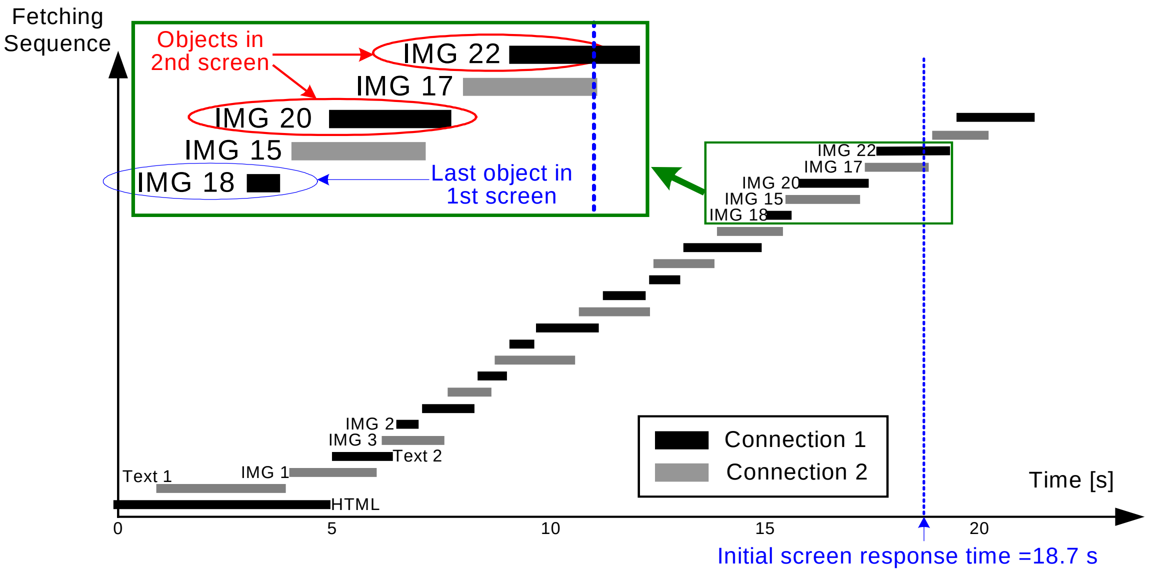
Screen Contention Problem (2)

- Simulation setup
  - *ns2* network simulator
    - *Reno-FullTCP* package: support for bi-directional transmissions
  - Link characteristics
    - Link between Web client and backbone network
      - 100-kbps bandwidth and 100-ms link delay.
    - From DNS/Web servers to backbone network
      - 1-Mbps bandwidth and 5-ms link delay
  - Browser Characteristics
    - The same Web statistics of *Top 50 Web Sites* are used.
    - Processing time per object: 200 ms.
    - HTTP request message size: 500 B.
    - HTTP/1.1 persistent connection: supported, pipelining: *not* considered.
    - Cache function: disabled.
  - Metric
    - Initial screen response time
      - Time spent until all objects for displaying the initial screen are downloaded completely

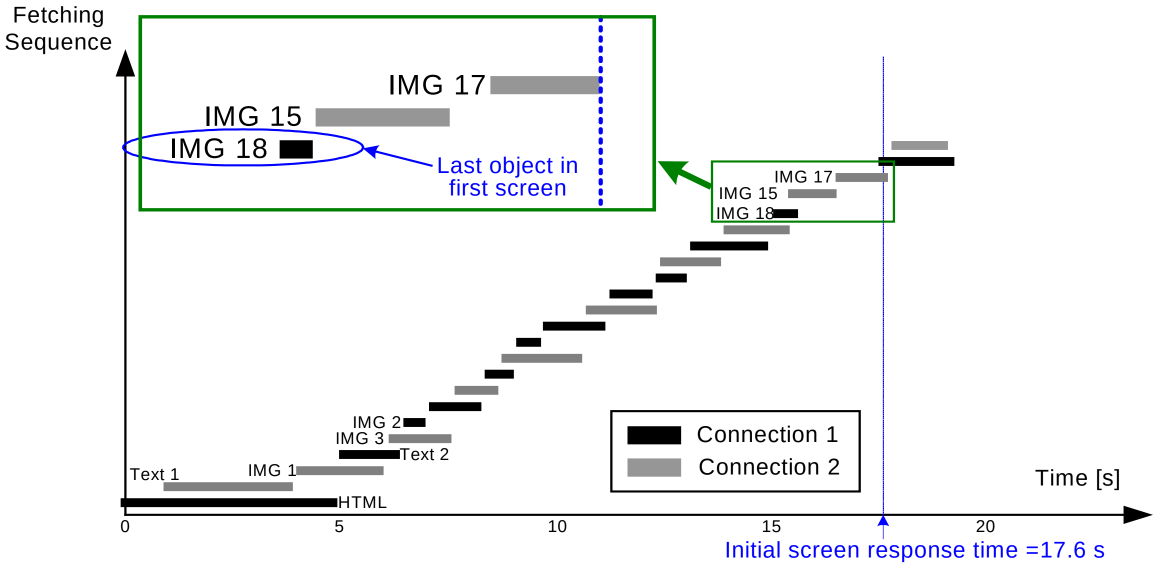
Screen Contention Problem (3)



- In this simulation,
  - All the objects are from a single server.
  - The initial screen has 18 on-screen objects.

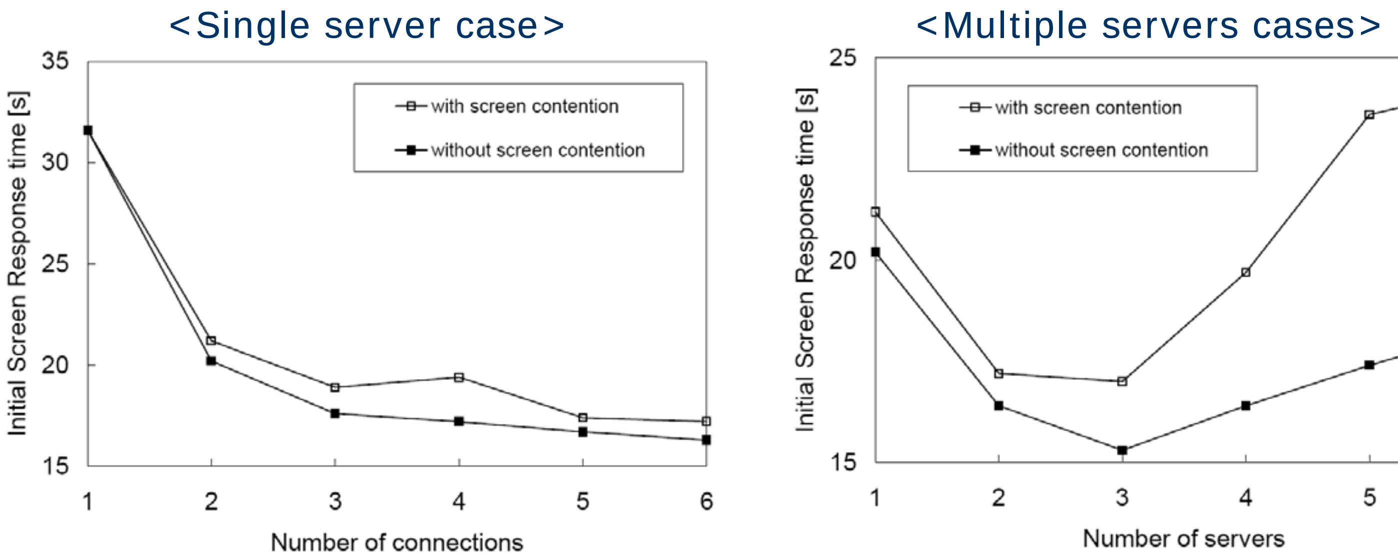
- Screen contention scenario
  - Two off-screen objects are fetched before the initial screen is fully displayed.
    - Fetching **unnecessary** objects consumes some portion of bandwidth
    - The resulting response time for initial screen is increased unnecessarily.

Screen Contention Problem (4)



- Ideal scenario
  - An intuitive solution is to prevent unnecessary object fetching.
    - When a faster connection completes all on-screen object transmissions, it stops fetching and waits for the other connections to finish fetching.
  - The remaining connections can obtain **more** bandwidth.
    - The response time for the current screen can be minimized.

Screen Contention Problem (5)

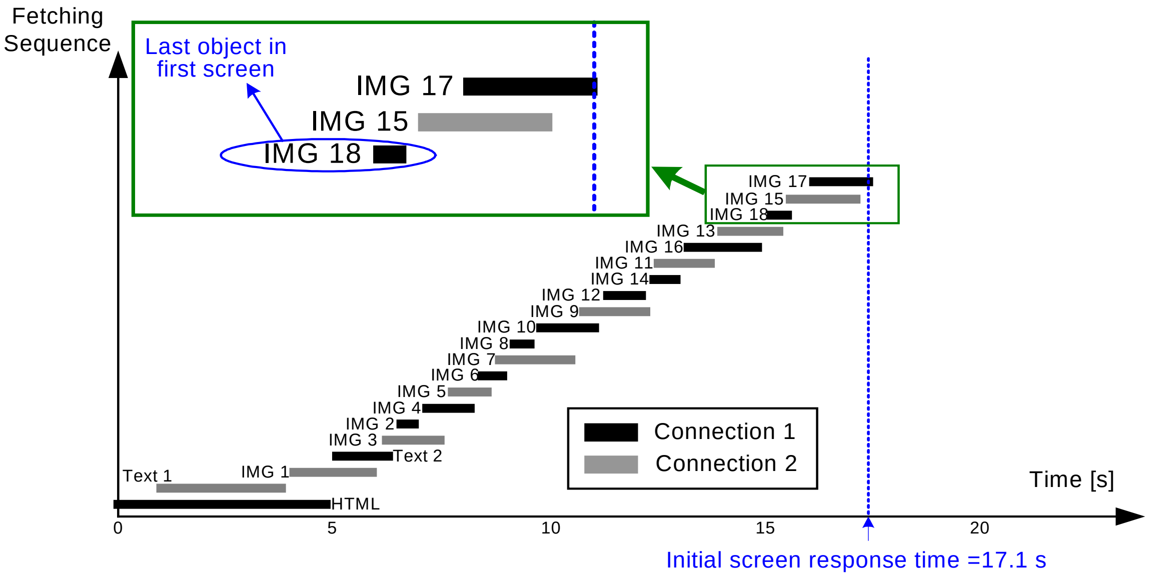


- Single server case (no load balancing)
  - The performance of both is not directly affected by the number of connections.
  - Number of connections = 3: the performance improvement is saturated.
- Multiple servers case (load balancing, up to 2 connections to server)
  - Number of servers > 3: the performance of the conv. Browser is degraded.
    - The degree of contentions among connections to different server becomes higher.
  - The performance in the ideal browser is **less** influenced by the number of servers.

Bandwidth Under-utilization (1)

- What is bandwidth under-utilization?
  - Idle time of a network increases with the decrease in the number of simultaneous active TCP connections.
    - An optimal number of simultaneous TCP connections exists.
  - A non-optimal number of active connections result in under-utilization of links.
    - We refer this to as the bandwidth under-utilization problem.
- Why does bandwidth under-utilization occur?
  - Current browsers do not maintain the optimal number active connections.
    - Only a small number of connections are active at any instant in a browser.
    - Other connections go into the idle status after completing all their object fetching.
  - In Web browsers, bandwidth efficiency is determined by how much the ending times of transmissions in all connections are synchronized.

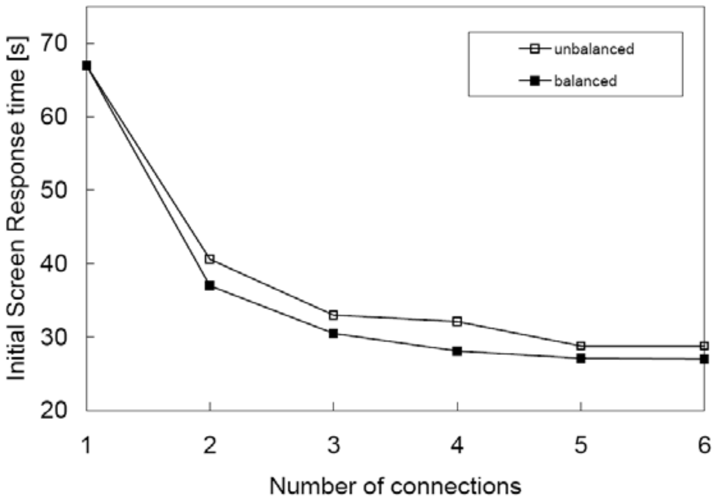
Bandwidth Under-utilization (2)



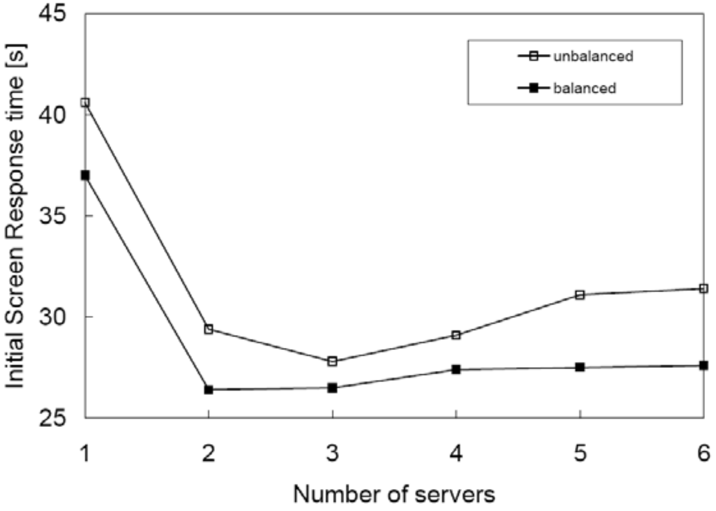
- Ideal case
  - The intuitive solution is to schedule different object requests across multiple servers such that as **many** connections are active as possible.
    - Each TCP connection should have at least one pending request in the message queue.
    - An inactive connection **takes over** the unfulfilled object requests from others.
  - Cooperative connections can use bandwidth more efficiently and improve the initial screen response time.

Bandwidth Under-utilization (3)

<Single server case>



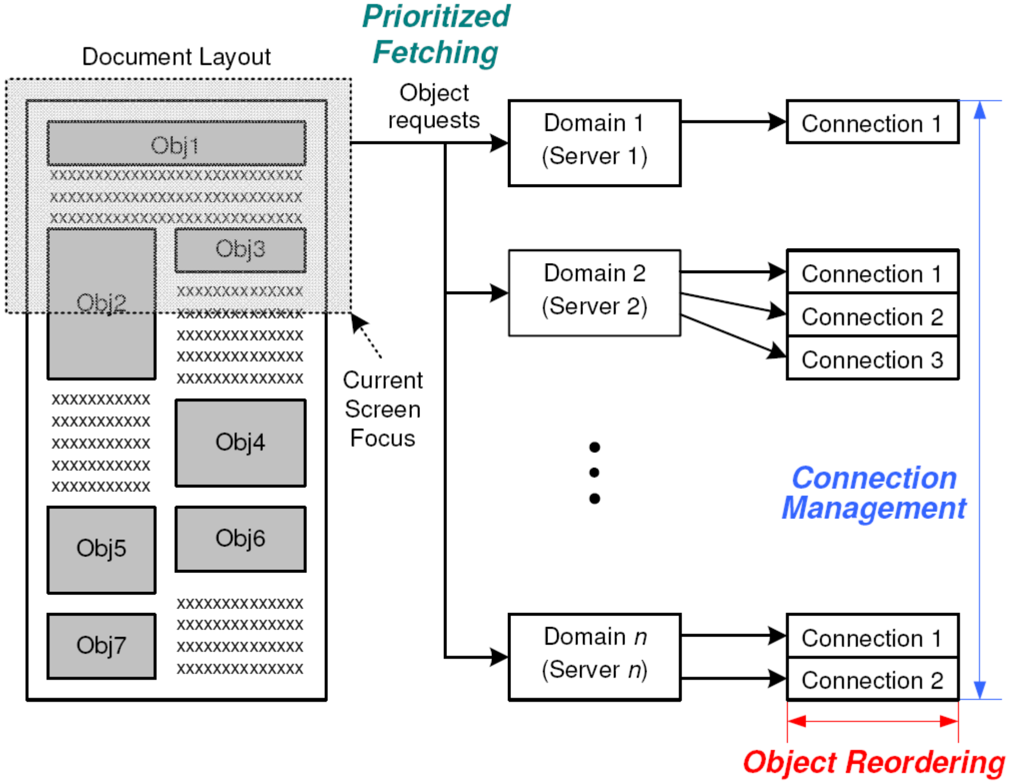
<Multiple servers case>



- In the simulations,
  - screen contention does not exist in this scenario.
- Single server case
  - The performance of both is not directly affected by the number of connections.
- Multiple servers case
  - With 2 or 3 (probably the optimal numbers) servers, both show the best performance.
    - As the number of servers increases beyond 3, performance rather becomes degraded.
  - The ideal scheme shows up to a 20% performance improvement.

Overview of Solution

- Prioritized fetching
  - Addresses the screen contention problem
  - Provides an optimization solution for fetching objects with varying priority levels.
  - *What-You-See-Is-What-You-Fetch* (WYSIWYF)
- Object reordering
  - Addresses the bandwidth under-utilization problem
  - Dynamically schedules object transmissions in a single connection
- Connection management
  - Also addresses the bandwidth under-utilization problem
  - Performs load balancing across multiple connections



Prioritized Fetching (PF) (1)

- Basic operation steps
  1) Obtain the initial screen view information in the entire document layout
  2) Prioritize embedded objects according to their locations in the layout
  3) Perform fetching objects according to their priority levels
     - When a user scrolls to a different view, repeat the process again.
- Initial object prioritization
  - Object-type-based prioritization
    - Text-based objects: HTML, javascript, cascading style sheets, etc.
      - They play an important role to construct the **overall HTML display layout**.
      - PF Gives the **highest** priority to these objects.
    - Other object types: Image (IMG) and multimedia objects, etc.
      - Different priority levels are given to objects according to their **locations**.
      - The **highest** priority level is assigned to **on-screen** objects.
  - Location-based prioritization
    - Detection of pixel size of objects
      - An HTML document file generally defines the pixel size of image objects.
      - In cases of no pixel size, PF uses an **averaged value** based on browsing history.
      - A Web browser can construct the full page layout without downloading these objects.

Prioritized Fetching (PF) (2)

  - Detection of location of objects
    - PF scans the document object model (DOM) tree. When it finds a target object, it
    1) searches all the successors in the tree
    2) calculates location offsets from successors to predecessors
    3) repeats the process until it reaches the top of the tree.
    - The absolute location in the layout is the **sum** of all the relative offsets.
- Selective object fetching
  - In HTTP, priority-based bandwidth allocation is not possible.
    - Connections perform **short bursty on-off transmissions** by sharing bandwidth.
    - A single TCP connection cannot send **both** high- and low-priority objects.
  - PF uses a delayed-transmission scheme.
    - PF inserts request messages into the already-in-use queues.
    - Low-priority objects begin to be fetched only after all the higher-priority queues become empty.
- Re-prioritization
  - When the screen focus is **moved to a new area**, PF re-prioritizes all the remaining objects in the queues for the newly focused area.
    - PF keeps the currently incoming transfers.

Objects Reordering (OR) (1)

- Basic operation steps
  1) Execute an initial assignment of objects
  2) Perform a TCP-aware ordering of objects
  3) Perform dynamic objects rescheduling
- Initial objects assignment
  - Conventional browsers perform byte-size-unaware round-robin assignments.
    - It causes unsynchronized ending times among different connections, and thus increases response time.
  - Initially, OR performs load balancing among connections by distributing the same amount of objects to every connection.
    - Expected ending time is given by $SizeData/BWavailable + n*rtt/2 + T_{Proc}$
      - n is the number of objects, and T_{Proc} is the processing time.
      - The first term **dominates** over other terms in low-bandwidth networks.
    - OR estimates the ending times by considering both the objects' pixel-size included in HTML document and the object formats, such as gif and jpg.

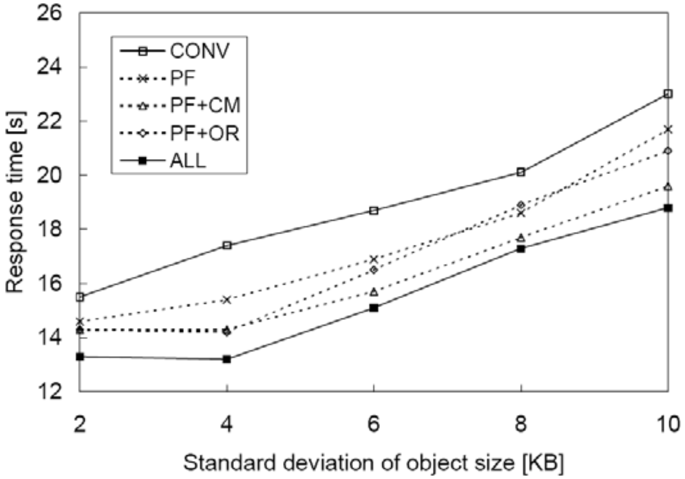
Objects Reordering (OR) (2)

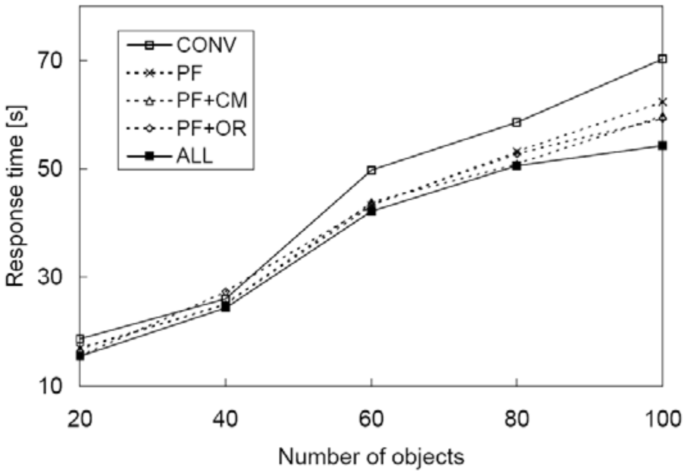
- TCP-aware objects reordering
  1) In TCP, appropriate ordering can minimize the adverse effect of **slow start**
     - 7-3-2 KB objects fetching takes 5 *rtt*s.(2+4+1+3+2 KB)   (if *cwnd* starts from 2)
     - 2-3-7 KB objects fetching takes 3 *rtt*s. (2+3+7 KB)
  2) Small objects can be rescheduled in a **finer** granularity.
     - With small objects being put at the end of connections, it is more likely to reschedule objects among connections.
  - Thus, OR orders the fetching sequence in a *rats-elephants-rats* fashion.
     - Data-size-based sorting
     - Size-based round-robin assignments
- Dynamic objects rescheduling
  - Because of dynamic behavior of TCP connections, the total fetching time of different connections may still vary significantly.
  - OR dynamically reschedules objects from the busy connections to the idle ones in an on-demand fashion.

Connection Management (CM)

- Basic operations step
  1) Estimate per-connection load
  2) Adjusting the number of connections for each server
- Per-connection load estimation
  - Estimation of the ending time of downloading
    - CM uses the byte-size information that OR converted earlier.
- Dynamic connection assignment
  - CM assigns more connections to servers with larger data size and less connections to servers with smaller data size.
    - The total number of connections is always maintained the same as in current browsers for friendliness and compatibility.
      - When it assigns one more connection to a server, one less connection should be deducted from some other server.
    - CM limits the maximum number of connections to a server to 4.
      - Allocating too many connections to the same server does not necessarily lead to better performance.

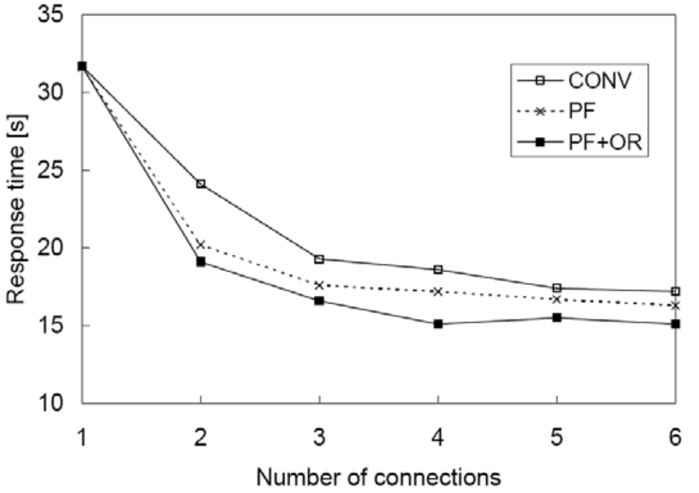
Performance Evaluation (1)

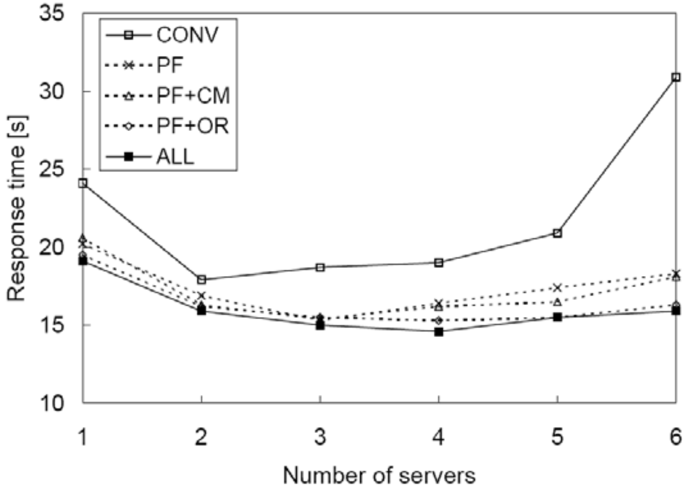




- Impact of object characteristics
  - Variance of object size
    - **Large** variance of sizes reduces bandwidth utilization.
  - Number of objects in a Web page
    - As more objects are included in a page, larger response time is expected.
  - Our solution reduces up to 30% of response time.

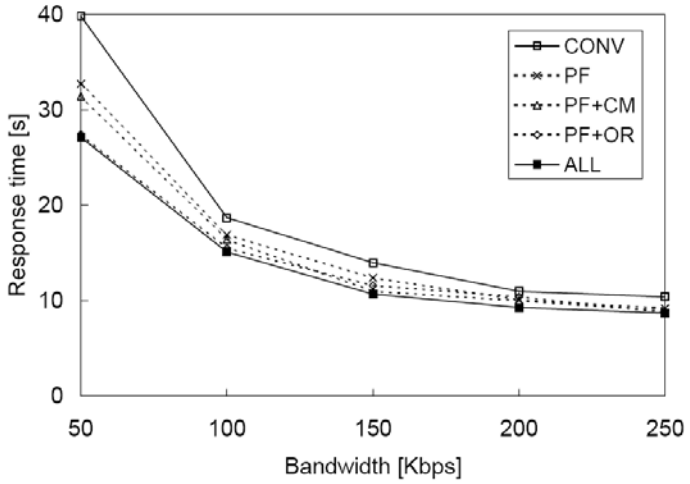
Performance Evaluation (2)

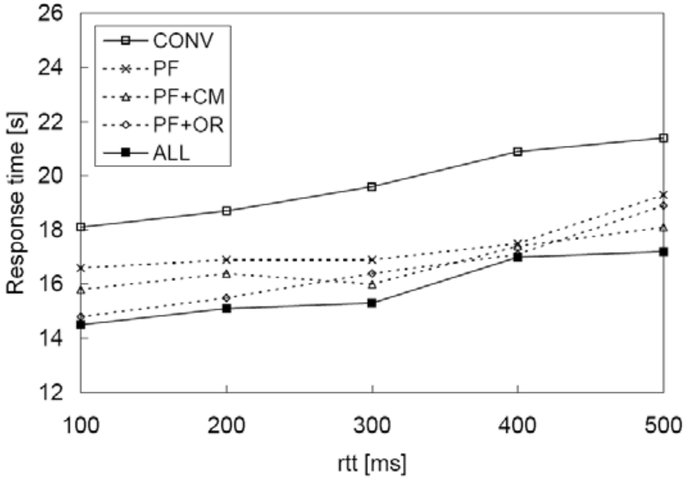




- Impact of number of connections/servers
  - Number of connections
    - Number of connections > 4: no obvious performance improvements in both
  - Number of servers
    - Number of servers > 3: performance begins to be degraded.
      - Increasing the number of servers does not necessarily always result in better performance
  - Up to 20% of response time can be reduced by using our solution.

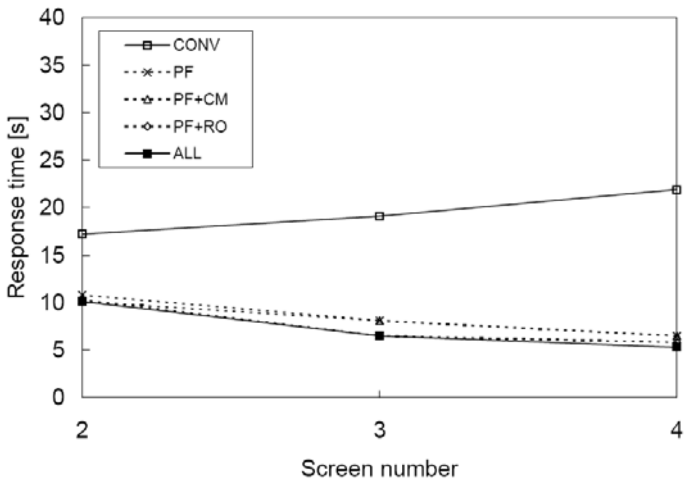
Performance Evaluation (3)





- Impact of network characteristics
  - Bandwidth
    - Our solution brings more performance improvement for smaller bandwidth.
      - Smaller bandwidth makes the screen contention problem more severe.
  - Round-trip time (*rtt*)
    - Our solution reduces the required number of *rtt*s for object transmission.
  - Around 20% performance improvement is achieved by our solution.

Performance Evaluation (4)



- Impact of fast scroll
  - In conventional browsers, when a user scrolls away from the initial screen, response time for that screen increases significantly.
    - Displaying of any screen requires downloading of **all previous screen**(s).
  - Our solution has smaller response time, as a user scrolls farther away.
    - PF always fetches the **current screen first** in an on-demand way.
    - In most Web pages, **less** data is located in farther screens.
  - Up to 70% of the response time can be reduced.

Conclusions

- In this paper, we explore the reasons that conventional web access models are not appropriate for low-bandwidth hosts.
  We identify the screen contention and bandwidth under-utilization problems, which result in large user-perceived response time.

- To address this problem, we propose a new Web access scheme for low-bandwidth hosts, which uses an intelligent mix of prioritized fetching, object reordering, and connection management.

- Using simulations with the statistics of *Top 50 Web Sites*, we evaluate the performance of our scheme and prove its benefits over conventional Web access models.